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Aeronomy Laboratory Precipitation Data Products

This document defines the Aeronomy Laboratory profiler precipitation data that are being made available to the NASA TRMM research community. This document outlines how these data products are determined from the original observations and also defines the format of the output files.

1. Precipitation Data Products

The precipitation observations made from the Aeronomy Laboratory profilers can be grouped into three different classes: original on-site recorded data, profiler derived precipitation data products, and special profiler derived data products. Each class is outlined below.

Original On-Site Recorded Observations

The original observations are recorded on-site. There are two types of original on-site recorded data: profiler and auxiliary observations. The profiler observations contain the measured Doppler spectra, moments, and pertinent profiler parameters. The auxiliary observations include surface rain gauge data, disdrometer data, and surface meteorological observations.

The original profiler data will be archived at the Aeronomy Laboratory and used to produce the Standard and Non-Standard Precipitation Data Products described below. The auxiliary observations will be archived at the Aeronomy Laboratory and at the NASA TRMM Office. The auxiliary data will be archived in their native data format.

Standard Precipitation Data Products

The Standard Precipitation Data Products are profiler derived precipitation data products. For each data record and range gate the equivalent reflectivity factor, the reflectivity-weighted mean Doppler velocity, and the spectral width are determined. The Standard Precipitation Data Products are determined for both the 915 and 2835 MHz profilers. These data products are archived at the Aeronomy Laboratory and at the NASA TRMM Office.

Non-Standard Precipitation Data Products
The Non-Standard Precipitation Data Products are value added products under development and are derived from the original profiler observations. The Non-Standard Precipitation Data Products will be available to collaborators upon special request. Scientists interested in Non-Standard Precipitation Data Products are expected to work in close collaboration with AL scientists. Two examples of Non-Standard Precipitation Data Products under development include multiple peak information and drop size distribution parameter estimates.

2. Determination of Standard Precipitation Data Products

The Standard Precipitation Data Products are derived from the original on-site recorded profiler observations. This section briefly describes how the Standard Precipitation Data Products are derived from the original observations and the format of the output files.

The Standard Precipitation Data Products are derived from the original spectra in the following 10 basic steps. These steps are outlined below and described in detail in the following pages.

1. Extract the moments from the original spectra.
2. Delete observations with signal-to-noise ratios less than the Threshold of Detectability.
3. For each profile, correct the signal-to-noise ratio for enhanced noise.
4. Calculate the equivalent reflectivity factor from the adjusted signal-to-noise ratio.
5. Adjust the equivalent reflectivity by the Time Domain Averaging (TDA) filter.
6. Define Doppler velocity such that downward motion is negative.
7. Determine the status of each observation and produce a status flag.
8. Write the data products in formatted ASCII files.
9. Name the ASCII files following a convention.
10. Compress hourly ASCII files to reduce file size and to group common files.

1. Extract moments from original spectra.
The moments used in the Standard Precipitation Data Products are determined on-site by the real time processing routine. These moments are retrieved from the recorded data using specially developed Profiler Data Access (PDA) routines.

2. Delete observations below the Threshold of Detectability.
The empirically derived Threshold of Detectability determines the minimum signal-to-noise ratio for atmospheric observations. All observations below this threshold are not considered to result from atmospheric scattering processes. The Threshold of Detectability is range independent, but can be converted into reflectivity, which is range dependent. The Threshold of Detectability, *threshold*, in log units is defined as:

$$threshold = 10\log\left(\frac{25\sqrt{NFFT - 2.3125 + \dfrac{170}{NPTS}}}{(NPTS)(NFFT)}\right) \qquad (1)$$

where NFFT is the number of FFTs averaged to produce the final spectra, and NPTS is the number of points in the spectra. Even if an observation has a signal-to-noise ratio less than the Threshold of Detectability, the output file contains the derived reflectivity, Doppler velocity and spectral width as well as a status flag indicating the observation is below the Threshold of Detectability.

3. For each profile, correct the signal-to-noise ratio for enhanced noise.
For Doppler spectra that span a large fraction of the Nyquist velocity range, there may not be enough spectral points to accurately represent the true noise level. For these broad Doppler spectra, the calculated noise may overestimate the true noise. Thus, the signal-to-noise ratio may be too low, and the subsequent equivalent reflectivity factor may also be too low. The Nyquist velocity is set to very large values (~17.5 ms^{-1}) to minimize this effect.

The goal is to replace the elevated noise values with a good estimate of the noise. Since the noise is range independent, the noise at the 10 highest range gates (where the spectra are not broad) are averaged to form an estimate of the true noise for that profile. The noise at each range is adjusted to produce an adjusted signal-to-noise ratio. This adjusted signal-to-noise ratio is used to calculate the equivalent reflectivity factor.

The mean noise at the 10 highest range gates is expressed

$$\overline{noise} = \frac{1}{10}\sum_{j=n-9}^{j=n} noise(j) \qquad (2)$$

where *noise(j)* is the noise in linear units at the j^{th} range gate and there is a total of *n* range gates. The noise and mean noise can be converted to log units using

$$noise_{\log}(j) = 10\log(noise(j)) \qquad (3)$$

$$\overline{noise_{\log}} = 10\log(\overline{noise}) \qquad (4)$$

The signal-to-noise ratio, *s2n(j)*, can be expressed in log units by

$$s2n_{\log}(j) \; = \; 10\log(s2n(j)) \tag{5}$$

where *s2n(j)* is in linear units expressed for each range gate. The adjusted signal-to-noise ratio, $s2n'_{\log}$, is calculated in log space using

$$s2n'_{\log}(j) \; = \; s2n_{\log}(j) \; + \; (noise_{\log}(j) \; - \; \overline{noise_{\log}}). \tag{6}$$

The adjusted signal-to-noise ratio is calculated in linear space using

$$s2n'(j) \; = \; \frac{s2n(j)\,noise(j)}{\overline{noise}}. \tag{7}$$

4. Calculate the equivalent reflectivity factor from the adjusted signal-to-noise ratio.
The liquid water equivalent reflectivity factor is determined from the adjusted signal-to-noise ratio and the range gate distance by

$$z_e(j) \; = \; \frac{\mathrm{PRC}}{\mathrm{NPW}^2\,\mathrm{NCI}} \; range(j)^2 \; s2n'(j) \tag{8}$$

where PRC is the Profiler Radar Constant, NPW is the pulse width in nanoseconds, NCI is the number of coherent integrations, *range(j)* is the range gate distance in meters, and $s2n'(j)$ is the adjusted signal-to-noise ratio expressed in linear units. The units of the PRC are defined such that the units of $z_e(j)$ are $mm^6\ m^{-3}$. Typically, PRC is a constant and reflects the hardware and software constants for a particular installation. The equivalent reflectivity factor can be expressed in log units by

$$Z_e(j) \; = \; 10\log(z_e(j)) \tag{9}$$

and has units of dBZe. All calculations are in reference to liquid water equivalent reflectivity factor. The minimum detectable reflectivity factor is defined using (8) and setting $s2n'(j)$ to the Threshold of Detectability.

5. Adjust the equivalent reflectivity by the Time Domain Averaging filter (TDA filter).
Coherent integration is a digital filtering process used by profilers. Coherent integration does not increase the signal-to-noise per unit bandwidth in the signal band, but it simply filters out much of the wideband noise. This digital filter is called the Time Domain Averaging filter (TDA filter). One side effect of using coherent integration is the decreased power return at frequencies different than zero Doppler shift. This decreased power follows the sinc function with a power

response of unity at zero Doppler velocity and the first null located at +/- 2 $v_{Nyquist}$ velocities. The power response for the TDA filter is expressed

$$|\mathrm{H}(v)|^2 = \frac{\sin^2\left(\dfrac{\pi v}{2 v_{Nyquist}}\right)}{NCI^2 \sin^2\left(\dfrac{\pi v}{2 v_{Nyquist} NCI}\right)} \tag{10}$$

where v is the velocity in ms^{-1}, and $v_{Nyquist}$ is the Nyquist velocity in ms^{-1} defined by

$$v_{Nyquist} = \frac{\lambda}{(4\ NCI\ IPP)} \tag{11}$$

where λ is the operating wavelength, and IPP is the inter-pulse period. The calculated equivalent reflectivity factor can be corrected by the inverse of the TDA transfer function and is expressed

$$z_{TDA}(j) = z(j)\ \frac{NCI^2 \sin^2\left(\dfrac{\pi V(j)}{2 v_{Nyquist} NCI}\right)}{\sin^2\left(\dfrac{\pi V(j)}{2 v_{Nyquist}}\right)} \tag{12}$$

where *z(j)* is the reflectivity at the jth range gate, and *V(j)* is the reflectivity-weighted mean Doppler velocity at the jth range gate. For simplicity, the subscript "TDA" is omitted in all references to the equivalent reflectivity factor, even though the correction has been applied.

6. Define Doppler velocity such that downward motion is negative.

The Doppler velocity recorded by the profiler is defined as positive motion toward the radar. The sign of the mean reflectivity-weighted Doppler velocity is inverted in the precipitation data products to be consistent with the meteorological convention of downward motion having a negative value.

7. Determine a status flag for each observation.

Each observation is assigned a integer status flag ranging from 0 to 10. The purpose of the status flag is to classify the observations. A status flag of 0 indicates the observation had a signal-to-noise ratio less than the Threshold of Detectability. A status flag less than 5 indicates a probable clear-air observation and a status flag greater than 5 indicates a probable precipitation observation. The status flags are defined in Table 1.

Table 1. Status Flag Definitions

Status flag	Description
0	Signal-to-Noise Ratio less than Threshold of Detectability. No atmospheric signal is detected.
1	Undefined
2	Weak Reflectivity with large upward motion. (Z_obs < Z_threshold) & (V_obs > abs(V_threshold)) Dominated by bad data points and interference. Low probability of atmospheric signal.
3	Weak Reflectivity without large downward motion. (Z_obs < Z_threshold) & (abs(V_obs) < abs(V_threshold)) Dominated by clear-air observations.
4	Undefined
5	Undefined
6	Undefined
7	Undefined
8	Strong reflectivity without large downward motion. (Z_obs >= Z_threshold) & (V_obs >= V_threshold)
9	Weak reflectivity with large downward motion. (Z_obs < Z_threshold) & (V_obs < V_threshold)
10	Strong reflectivity with large downward motion. (Z_obs >= Z_threshold) & (V_obs < V_threshold)

Note: V_threshold is a negative value.

As an example of using the Doppler velocity and reflectivity thresholds to identify the precipitation observations, Figure 1 shows the reflectivity versus Doppler velocity scatter plot at 2.14 km above Kapingamarangi during TOGA COARE. The scatter plot shows the grouping of observations around two different clusters. One cluster represents the hydrometeor motions with downward motions ranging from approximately -2 to -10 ms^{-1}. The other cluster represents clear-air motions and the motions in the turbulent boundary layer. There are two constant thresholds drawn in Figure 1, one for reflectivity and the other for Doppler velocity. While the Doppler velocity and reflectivity thresholds shown in the figure don't divide the clusters perfectly, the two thresholds define five sections in this reflectivity-Doppler velocity space.

Without having a more complete data set available, optimum thresholds to divide the clusters are not possible. We adopt conservative estimates of these thresholds and anticipate improving the separation in the future. Ultimately, the Doppler velocity and reflectivity thresholds are altitude dependent. For the TRMM data sets, the Doppler velocity threshold is determined using the rules listed in Table 2. A transition in V_threshold occurs at 3.0 km. This transition level is conservative and it is expected that some turbulent motions will be assigned a status flag of #9 between 3.0 km and the true melting level. The reflectivity threshold, Z_threshold, is independent of altitude in this version and held constant at 20 dBZe.

Table 2. V_threshold as a function of Altitude

Altitude	Description
Below the melting level, height <= 3.0 km	V_threshold = -2.0 m/s
Above the melting level, height > 3.0 km	V_threshold = -0.5 m/s

8. Write the final products in formatted ASCII files.
The Standard Precipitation Data Products are written as ASCII files. Each file contains the observations and parameters for one hours worth of observations. The output file is a 2-dimensional matrix. Each row of the matrix is an independent observation, and each column is a different variable or parameter. The contents and format of each column in the output file is described in Table 3. There is one blank space between each formatted column and all values are padded with leading zeros to maintain the specified format.

Table 3. Contents and Format of Standard Precipitation Data Products

Column	Mnemonic	Units	Format
1	year	years	I4 (xxxx)
2	Day-of-year	days	I3 (xxx)
3	Hour-of-day	hours (UTC)	I2 (xx)
4	Minute-of-hour	minutes	I2 (xx)
5	Second-of-minute	seconds	I2 (xx)
6	Frequency	MHz	I4 (xxxx)
7	PRC (Profiler Radar Constant)	N/A	F6.2 (xxx.xx)
8	Site Longitude	Degrees East	F7.2 (-xxx.xx)
9	Site Latitude	Degrees North	F6.2 (-xx.xx)
10	Pulse Length	meters	I4 (xxxx)
11	Range Gate Height	meters above Mean Sea Level (MSL) (center of range gate)	I5 (xxxxx)
12	Minimum Detectable Reflectivity	dBZe	F6.2 (-xx.xx)
13	Reflectivity	dBZe	F6.2 (-xx.xx)
14	Doppler Velocity	ms^{-1}	F6.2 (-xx.xx)
15	Spectral Width	ms^{-1}	F5.2 (xx.xx)
16	Status Flag	integer	I2

A sample of the Standard Precipitation Product output file from one time and the first 30 range gates is shown below:

```
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 00212 -27.35 -25.75 -02.52 02.71 09
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 00317 -23.72 -15.19 -01.02 00.60 03
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 00422 -21.16 001.73 -00.75 00.32 03
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 00527 -19.19 -05.82 000.80 00.37 03
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 00632 -17.58 003.63 000.57 00.37 03
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 00737 -16.23 005.80 001.04 00.90 03
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 00842 -15.06 013.64 000.91 01.31 03
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 00947 -14.03 010.75 001.08 00.89 03
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 01052 -13.10 -02.78 001.12 00.73 03
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1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 01157 -12.27 -17.52 003.43 00.22 00
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 01262 -11.51 -14.15 001.29 00.43 00
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 01367 -10.81 -05.68 001.09 00.42 03
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 01472 -10.16 -13.86 001.10 00.21 00
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 01577 -09.56 -10.65 -09.95 00.75 00
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 01682 -09.00 -06.07 001.16 00.40 03
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 01787 -08.47 -05.43 001.11 00.30 03
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 01892 -07.97 -06.15 001.11 00.27 03
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 01997 -07.50 -10.38 001.00 00.41 00
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 02102 -07.05 -00.41 000.77 00.80 03
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 02207 -06.62 -03.82 000.88 00.85 03
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 02312 -06.22 -01.56 000.95 01.55 03
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 02417 -05.83 -07.43 013.31 00.50 00
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 02522 -05.46 -05.36 000.20 01.46 03
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 02627 -05.10 -06.85 000.39 00.94 00
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 02732 -04.76 -08.98 013.99 00.22 00
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 02837 -04.43 -07.78 019.08 00.72 00
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 02942 -04.12 -07.63 007.84 00.32 00
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 03047 -03.81 -12.11 -04.88 00.19 00
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 03152 -03.52 -06.12 019.72 00.19 00
1998 108 00 00 31 0915 026.00 -095.27 029.78 0105 03257 -03.23 -06.45 -09.40 00.52 00
```

9. Name the ASCII files following a convention.

The output ASCII file is named following the convention:

sss_ffff_yyyy_ddd_hh_vx.dat

where the relationship between the memonics and the contents are listed in Table 4.

Table 4. Naming Convention Decoding Matrix

Designator	Meaning	Options	Description
sss	Site Name	tex flo bra kwa	Houston, Texas Triple N Ranch, Florida Ji-Parana, Brazil Kwajalein, Marshall Islands
ffff	Frequency	0915 2835	915 MHz profiler 2835 MHz profiler
yyyy	Year	1998-2000	Year
ddd	Day-of-year	001 to 366	Day-of-year
hh	Hour of day	00 to 23	Hour of day (UTC)
vx	Version	v1	Version 1. Released: 30 June 1998
.txt	ASCII file	.txt	File Extension

Note that all letters are in non-capitals. Here are two examples of the file naming convention:

File Name	Translation
tex_0915_1998_098_17_v1.txt	Houston, Texas; 915 MHz profiler; year 1998; day-of-year 98; hour-of-day 17; Version 1; ASCII format.
Flo_2835_1998_240_04_v1.txt	Triple N Ranch, Florida; 2835 MHz profiler; year 1998; day-of-year 240; hour-of-day 4; Version 1; ASCII format.

10. Compress hourly ASCII files to reduce file size and to group common files.
The ASCII files for each day consists of up to 24 hourly files. To save disk space and to organize the files, these ASCII files are 'zipped' using the PC 'zip' command.

The naming convention of the daily zip file is:

sss_ffff_yyyy_ddd_vx.zip

where the mnemonics are the same as listed in Table 4, and the extension '.zip' indicates a zip file.

Here are two examples of the zipped file naming convention:

File name	Translation
tex_0915_1998_098_v1.zip	Houston, Texas; 915 MHz profiler; year 1998; day-of-year 98; Version 1; zip format. Contents are zipped hourly files.
flo_2835_1998_240_v1.zip	Triple N Ranch, Florida; 2835 MHz profiler; year 1998; day-of-year 240; Version 1; zip format. Contents are zipped hourly files.

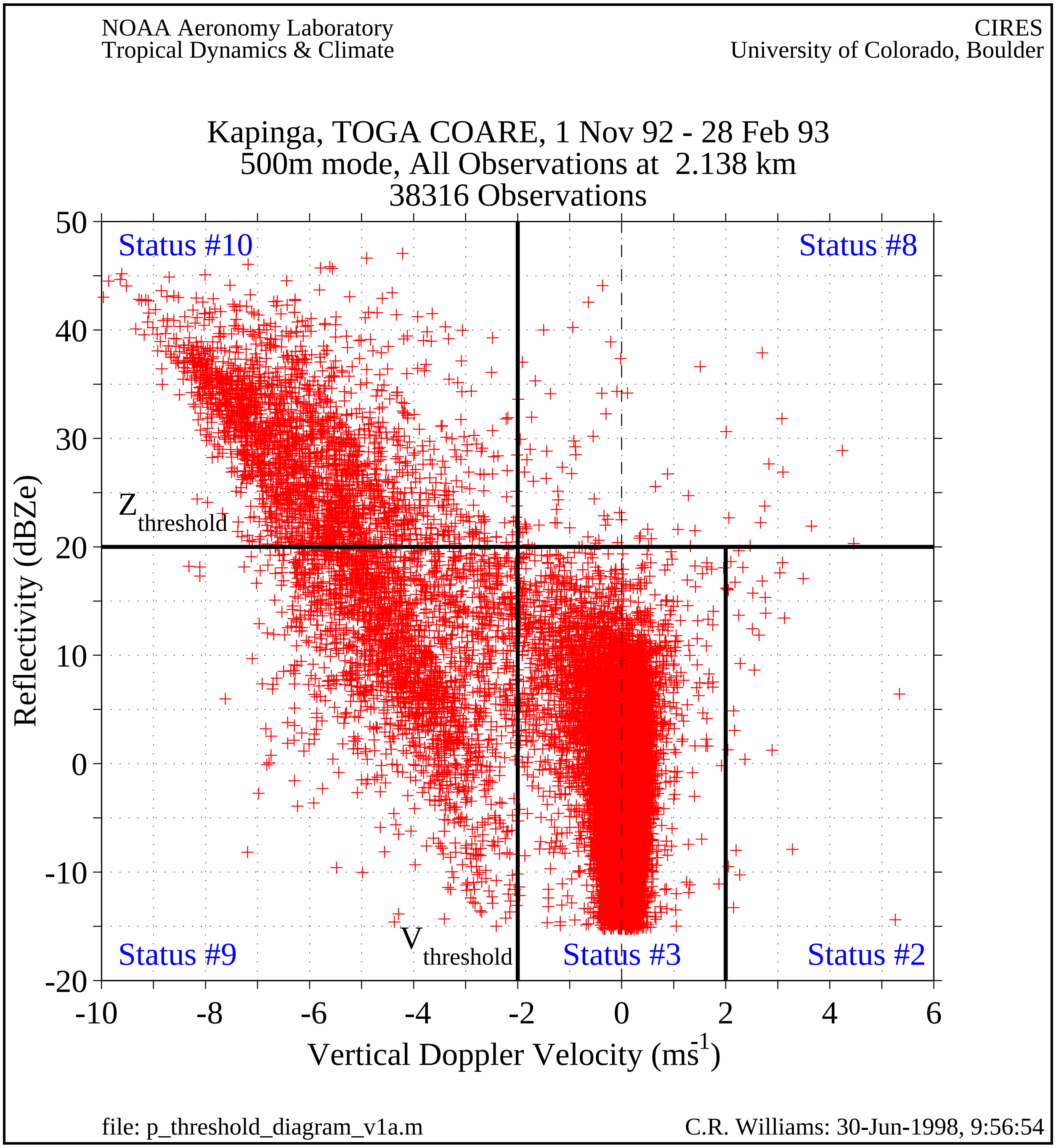

Figure 1. Scatter plot 915 MHz profiler observed vertical Doppler velocity versus equivalent reflectivity at 2.138 km above Kapingamarangi during TOGA COARE (1 Nov 92 through 28 Feb 93). The velocity and reflectivity thresholds are drawn. The status flags for #2, #3, #8, #9, and #10 are also indicated.